

CONTRACT NAS 3-6220

EXTENDED LOADING OF CRYOGENIC TANKS

QUARTERLY PROGRESS REPORT NO. 4

Covering Period

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Prepared by

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Cleveland, Ohio

This program is very closely related to the NASA Contract NAS 3-4194 and is designed to investigate the behavior of crack-like defects under sustained, rather than cyclic, loading conditions as is the case with NAS 3-4194 program. The experimental approach is based upon Griffith-Irwin fracture criteria and utilizes surface flawed fracture toughness specimens of 2219-T87 aluminum and 5Al-2.5Sn(TI) titanium. The specimens will be tested at -423°F, -320°F, and at room temperature, under static and sustained loading conditions. The obtained data will be integrated with cyclic data from NAS 3-4194 program and presented in the form useful in design of cryogenic pressure vessels.

During the time interval prior to this reporting period three quarterly progress reports have been written. The first report presented a detailed discussion of the instrumentation approach to be used for detection of flaw growth in surface flawed specimens during actual testing under sustained loadings. A sample fractograph showing clearly defined low-stress cyclic marking of a flaw growing under sustained loading in a 35-inch diameter tank was also included. The second quarterly progress report was devoted to technical redirection of the program. All room temperature testing of 5Al-2.5Sn(TI) titanium under sustained loading has been replaced with testing of both materials (5Al-2.5Sn(TI) Ti and 2219-T87 aluminum) at -320°F in the environment of liquid nitrogen under combined cyclic-sustained loading conditions. In the third quarterly report some experimental data was presented along with the detailed description of load levels and hold time sequences for individual specimens. Among the data listed in the third report were static fracture toughness of 5Al-2.5Sn(TI) titanium at -320°F and -423°F test temperatures. Some data were also obtained for 5Al-2.5Sn(TI) titanium at -320°F under sustained as well as combined cyclic-sustained loading conditions.

During the present reporting period all testing of 5Al-0.5Cr(III) titanium at -320°F and at -403°F test temperatures has been completed. This includes determination of uniaxial mechanical properties, static fracture toughness, sustained flaw growth characteristics, and combined cyclic-sustained flaw growth data. Mechanical properties and static fracture toughness data are listed in Tables I and II, respectively.

Combined cyclic-sustained flaw growth data for 5Al-0.5Cr(III) titanium at -320°F are listed in Tables III, IV, and V. Cyclic flaw preparation column in these tables shows temperature, maximum cyclic stress, and number of cycles required to extend initial EDM flaw in each specimen. The remaining columns list initial and critical flaw sizes, cyclic frequency, test temperature, and maximum cyclic stress level used for testing. The minimum to maximum stress level was in all cases ^{was} about 0.05. Cyclic frequency of one cycle per minute was generated using trapezoidal loading profile identical to the one used on NAD 3-4124 program. Five cycles per minute were generated by trimming sinusoidal profile at the top and bottom of the sinusoidal curve so that approximately equal intervals of time were spent on loading, unloading, as well as at maximum and minimum load. The 30 to 3½ cyclic frequency were purely sinusoidal. The slow frequency of 0.3 and 0.03 cycles per minute were generated by increasing time at maximum load to 0.5 and to 30 minutes respectively. The time to load, unload and at zero load were held at 15 seconds each.

Generation of sustained flaw growth data for 5Al-0.5Cr(III) titanium at -320°F was shifted from a "constant stress-variable flaw size" to "variable stress-constant flaw size" approach because of the relatively high threshold stress intensity level indicated during earlier testing. The flaw sizes selected were such that for the smallest flaw the stress required to precipitate sustained load stress failure still would be within the elastic stress range and that the largest initial flaw would not result in sustained flaw

growth fracture with critical flaw depth considerably exceeding one-half the material thickness.

Sustained flaw growth data for 5Al-2.5Sn(III) titanium tested at -320°F are listed in Tables VI through XII. The column showing cyclic flaw preparation or "marking", was used to list temperature, maximum stress, and number of cycles needed to extend EDM flaw. The same column is also used in cases when low-stress cyclic loading was used to mark flaw front after a given sustained load test sequence. Almost exclusively cyclic flaw extension and marking were done at room temperature. However, most of the specimens were brought to failure at -320°F. Some specimen dimensions are yet to be filled in the column on specimen size as well as cyclic flaw extension data for extension of EDM flaw. All EDM flaws were extended by cyclic fatigue. Whenever possible, initial and critical flaw dimensions are listed for each specimen. There are numerous instances, particularly for interrupted or mixed loading mode (incremental load increases with or without concurrent marking), where intermittent or even critical flaw sizes were not established. In such cases the corresponding lines in the columns for flaw size were left blank. Presently all specimens are undergoing a thorough examination and analysis and some of the missing information will become available at a later date.

Sustained flaw growth data for 5Al-2.5Sn(III) titanium at -423°F are listed in Tables XIII through XVI. The data are presented in the same form as were the -320°F sustained flaw growth data. Some of the unlisted information is yet to be abstracted from the laboratory records and added to the tables at a later date.

Testing of 2219-T7 aluminum under static, sustained and combined cyclic-sustained loading conditions has been completed except for a few specimens to be yet tested at -423°F. Testing of aluminum at -423°F was interrupted

due to hydrogen explosion in the test area. There were no injuries to the attending personnel but the test site was severely damaged. Arrangements were made to provide temporary test facilities in the remote Tulalip Test Site and the testing was resumed. Standard mechanical properties of the 2219-T87 aluminum are listed in Table XVII. Static fracture toughness at room temperature, -320°F, and at -423°F test temperatures are listed in Table XVIII.

Combined cyclic-sustained test data generated at -320°F are listed in Tables XIX and XX. The loading profiles for corresponding frequencies were exactly the same as used for titanium specimens.

Sustained flaw growth data for 2219-T87 aluminum tested at room temperature, -320°F, and -423°F test temperatures are listed in Tables XXI through XXVI for room temperature, Tables XXVII through XXIX for -320°F, and Tables XXXI through XXXII for -423°F test temperature. The test data for 2219-T87 at -423°F is not yet complete. For the most part, sustained data for 2219-T87 at all three test temperatures has been generated by resorting to intermittent flaw size marking at different stress intensity levels after a given sustained load run of several hours or days. Initial flaw sizes, intermittent marking, and critical flaw outlines are more often than not clearly defined permitting precise determination of stress intensity levels and sustained flaw growth rates.

During the course of sustained load testing of titanium, several specimens were instrumented for the detection of flaw opening during sustained load testing. Two 5Al-2.5Mn(TI) titanium specimens, No's. 4T-11 and 5T-12, were instrumented for manual read-out of opening displacements. Titanium specimens Nos. 5T-10, 5T-46, 6T-21, 6T-33, 8T-3, 9T-29, and 9T-23 were instrumented for a continuous plot of flaw opening versus time at load.

The entire set of flaw opening displacement data is being analyzed at the present time and has not yet been reduced.

Similar plots of flaw opening displacement versus time were also obtained for 2219-T87 aluminum. Specimens No's. CA-34 and DA-33 were instrumented and tested at room temperature. Specimen Nos. AI-59 and DA-36 were tested at -320°F. In each case plots were orderly and appear to be suitable for determination of the mechanics of flaw opening under sustained loading. The 2219-T87 aluminum flaw opening displacement data is likewise undergoing a detailed examination and analysis.

During a recent visit of the LRFB manager to the Seattle area, some tentative results of titanium and aluminum data analysis were discussed. Definition of threshold stress intensity levels of both materials at all test temperatures, possible influence of stress level upon flaw growth under a given stress intensity, and correlation of flaw opening displacements with actual flaw growth were among topics discussed.

During the next reporting period experimental portion of the program will be completed. Analysis of uniaxial, as well as biaxial, data will be completed and formulated. Timely coordination and direct participation of the LRFB Manager in judicious programming of remaining test sequences appears to have strengthened the belief that basic program objectives will be fulfilled on time and within available budget.

C. P. Tiffany
Project Supervisor

PMI/cks

CONTRACT SUMMARY

NAS 3-6290

G - 64

1985

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
TASK I - UNIAXIAL TESTING																								
DEVELOPMENT OF TEST INSTRUMENTATION																								
SPECIMEN FABRICATION																								
SPECIMEN TESTING																								
TASK II - DESIGN AND FABRICATION																								
TOOLING																								
TANKS																								
TEST FIXTURES																								
TASK III - BIAXIAL TESTING																								
TASK IV - ANALYSIS																								
COMPARISON OF DATA																								
DEFINITION OF DESIGN METHODS																								
REPORTS																								
FIRST DRAFT																								
FINAL REPORT																								
COORDINATION TRIPS																								
MATERIAL ORDERED																								
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UNIAXIAL TEST COMPLETE																								
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MONTHLY REPORTS																								
QUARTERLY REPORTS																								
CONTRACT AWARDED																								
ROUGH DRAFT																								
FINAL REPORT																								
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PERIOD	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
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PLANNED	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	125	

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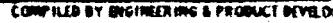
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1 INCLUDES COMMITTED TO
2 REVISED TO REFLECT TECHNICAL
REDIRECTION.

TABLE I
STANDARD MECHANICAL PROPERTIES OF 5A1-2.5 SW(ELI) TITANIUM.

SPECIMEN SIZE	GRAIN ORIENTATION	TEST TEMPERATURE (°F)	GAGE THICKNESS (IN.)	GAGE WIDTH (IN.)	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONGATION (% IN GAGE LENGTH SHONN)	LENGTH GAGE	
								ONE INCH	TWO INCHES
TT-1	E.R.	7	.2	.5	119.2	110.0			
TT-2	-320	7	.2	.5	192.6	180.2			
TT-4	-423	7	.2	.5	224.3	209.2			
TT-3	-423	7	.2	.5	228.7	—			

TABLE II
UNIAXIAL STATIC FRACTURE TOUGHNESS OF $SAC-2.5Sn(Eu)$ TITANIUM

SPECIMEN IDENTIFICATION		THICKNESS (t)	WIDTH (W)	TEST TEMPERATURE (°F)	FLAW DEPTH (a)	FLAW LENGTH (2c)	FLAW SIZE (a/g)	FRACTURE STRESS (ksi)	KC ~ KSI/IN	REMARKS
SPECIMEN SIZE (in.)										
9T-9	.193	2.00	-320	.112	.380	.073	111.5	-	58.7	
6T-5	.195	2.00	-320	.059	.259	.049	172.9	-	74.2	
5T-11	.192	2.00	-320	.056	.185	.040	177.4	-	69.2	
5T-38	.202	2.00	-320	.052	.179	.037	177.1	-	66.7	
6T-37	.202	2.00	-423	.064	.225	.043	133.0	-	53.9	
5T-25	.200	2.00	-423	.054	.204	.038	145.0	-	55.1	
9T-40	.202	2.00	-423	.090	.332	.060	92.7	-	44.3	

TABLE III
COMBINED CYCLIC FLAW GROWTH DATA FOR 500-2.5% (E₁₁) TR
@ -320°F

SPECIMEN SIZE	CYCLIC FLAW PREPARATION	INITIAL FLAW SIZE	CYCLIC TEST	CRITICAL FLAW SIZE		FLAW LENGTH (IN)	FLAW DEPTH (IN)	FLAW DEPTH @ 0% FLAW SIZE (IN)	FLAW LENGTH (IN)	FLAW DEPTH @ 50% FLAW SIZE (IN)	FLAW LENGTH (IN)	FLAW DEPTH @ 100% FLAW SIZE (IN)
				FLAW DEPTH @ 0% FLAW SIZE (IN)	FLAW DEPTH @ 50% FLAW SIZE (IN)							
3T-4 .195 2.00 RT	40.0	71,000	.039 .092 .020	-320	171.0 .3	.059	.147	.032	47	47.3	59.7	
3T-47 .200 2.00 RT	40.0	70,000	.037 .132 .027	171.0 .03	.058	.157	.034	.3/3	54.6	61.7		
3T-2 .196 2.00 RT	40.0	70,000	.045 .123 .027	171.0 5	.077	.177	.039	9.5	54.6	65.7		
3T-45 .204 2.00 RT	40.0	90,000	.046 .138 .029	171.0 1	.078	.183	.041	76	56.7	67.4		
3T-43 .202 2.00 RT	40.0	90,000	.050 .151 .033	-320	175.0 .30	.066	.167	.037	47	62.1	65.5	
3T-7 .196 2.00 RT	40.0	71,000	.040 .141 .029	-320	162.2 .34	.084	.198	.043	450	53.8	65.8	
3T-8 .195 2.00 RT	40.0	80,000	.044 .136 .029	162.2 1	.092	.212	.046	2.31	53.8	68.0		
3T-10 .194 2.00 RT	40.0	70,000	.049 .147 .031	162.2 5	.097	.215	.047	3.38	55.7	68.6		
3T-50 .207 2.01 RT	40.0	55,000	.045 .128 .027	-320	162.2 .3	.087	.219	.048	166	51.9	69.3	

TABLE II
COMBINED CECIC FLAW GROWTH DATA FOR SAR-2.5 fm (EEL) TEST

SPECIMEN NUMBER	NUMBER OF CYCLES	THICKNESS (IN.)	WIDTH (IN.)	WIDTH OF TEMP.	MAX STRESS (KSI)	NUMBER OF CYCLES OR FLAW DEPTH	FLAW LENGTH OR CRITICAL SIZE	CYCLIC FLOW TEST	CYCLIC FLOW TEST	CRITICAL SIZE	CRITICAL FLOW	
											FLAW DEPTH (IN.)	FLAW LENGTH OR CRITICAL SIZE
5T-19	.19	.94	2.00	2T	40.0	30,000	.063	.194	.039	-320	138.9	1
5T-13	.19	.94	2.00		49,000	0.52	.196	.038		2	.111	.263
5T-27	.202	.202	2.00		30,000	0.54	.200	.039		5	.106	.265
5T-28	.199	.99	2.00		35,000	0.62	.184	.038		34	.095	.242
5T-35	.197	.97	2.00		28,000	0.60	.203	.040		34	.121	.292
5T-26	.201	.201	2.00	RT	40.0	25,000	.047	.182	.033	-320	138.9	.03
											.120	.270
											.058	.409
											.050	.49.0

TABLE IV
COMBINED CYCLIC FLAW GROWTH DATA FOR STAINLESS STEEL IN
-320°F

SPECIMEN NUMBER	NUMBER OF CYCLES	MAX. STRESS	TEMP. OF TEST	WIDTH (IN.)	THICKNESS	NUMBER OF CYCLES OF	MAX. LENGTH	FLAW DEPTH	FLAW LENGTH	FLAW SIZE	(N.R./N) 227						
											INITIAL FLAW SIZE (IN.)	CYCLIC TEST	FLAW DEPTH (IN.)	FLAW LENGTH (IN.)			
8T-31	.197	2.00	RT	40.0	.12,000	.064	.271	.049	-320	133.0	1	.115	.253	.054	67	57.6	60.2
8T-42	.194	2.00	RT	15,000	.079	.282	.055	1	133.0	.5	.096	.306	.062	21	60.9	64.6	
8T-41	.199	2.00	RT	15,000	.079	.277	.054	1	133.0	.34	.102	.339	.067	9*	60.4	67.2	
8T-16	.194	2.00	RT	13,000	.079	.296	.057	1	133.0	.03	1	133.0	.03	1	62.0		
8T-49	.202	2.01	RT	10,000	.086	.327	.060	1	110.7	.03	1	110.7	.03	1	52.9		
8T-52	.205	2.00	RT	14,000	.087	.284	.057	1	132.7	.3	1	132.7	.3	1	61.8		
8T-57	.206	2.01	RT	10,000	.090	.301	.059	1	123.3	.3	1	123.3	.3	1	58.4		
8T-73	.201	2.00	RT	10,000	.070	.267	.051	1	133.0	.3	.099	.315	.063	95	58.6	65.1	
8T-55	.202	2.01	RT	8,000				1	132.0	.03	1	132.0	.03	1			
8T-56	.206	2.00	RT	5,000				1	133.0	.03	1	133.0	.03	1	2		
8T-62	.206	2.01	RT	40.0	7,000	.070	.324	.056	-320	133.0	.03	.085	.319	.061	47	61.5	64.1

* THIS SPECIMEN OVERLOADED TO 140.5 KSI IN 500 CYCLES TOTAL NINE CYCLES TO FAILURE

1 FRACTURED UPON LOADING

2 LN₂ SUPPLY WAS ACCIDENTALLY INTERRUPTED, SPECIMEN WARMED UP AND FRACTURED

TABLE III
SUSTAINED FLAW GROWTH DATA FOR 5 Al-2.5 Sn (EEL) TITANIUM
@ -320 °F

* No. FA12012

► PULLED TO FAILURE

2

TABLE VII
SUSTAINED FLAW GROWTH DATA FOR 5Al-2.5Sn(EL) TITANIUM
@ 320 °F

SPECIMEN SIZE	CYCLIC FLAW PREPARATION OR MARKING	INITIAL FLAW SIZE	SUSTAINED TEST	CRITICAL FLAW SIZE	
				KIc (ksi) FLAW 3215 M872	KIc (ksi) FLAW LENGTH 2C ~ (in)
ST-20 .194 2.00 RT	40.0 25,000 .054	.198 .039	-320 165.2	3.1 .072 .204	0.44 63.8
ST-18 .193 2.00 RT	40.0 23,000 .052	.191 .039	-320 165.0	3.40 .066 .218	0.45 63.7
ST-46 .200 2.00 RT	40.0 28,000 .052	.166 .035	-320 165.2	16.8* -320 173.5	60.2
		- - -	- - -	0.17 .061	0.00 .042
					66.0

* NO FAILURE

TABLE III
SUSTAINED FLAW GROWTH DATA FOR STAR-2.5 Sn(EO) TITANIUM
② - 320°F

* NO FAIR USE

PULLED TO FAILURE

BROOK UPON LOADING

TABLE IX
SUSTAINED FLAW GROWTH DATA FOR 541-2.5 E_{11} TITANIUM
@ -320°F

SPECIMEN SIZE	CYCLIC FLAW PREPARATION OR MARKING	INITIAL FLAW SIZE	TEST	SUSTAINED TEST	CRITICAL FLAW SIZE	KIc (KSI) KIc (KSI)					
						TEST TEMP (°F)	MAX STRESS (ksi)	TIME @ Gmax (hrs)	FLAW DEPTH a ~ (in)	FLAW LENGTH 2c ~ (in)	FLAW SIZE a/2 ~ (in)
GT-21	.194 2.00	RT	40	15,000 .063	.224	0.45	-320	156.8	22.7*	-	64.8
			-	-			-320	164.6	.4	.075	.241 .050
GT-3		RT	40.0	10,000	.089	.298	320	117.3	119.7*	.089	55.1
		RT	40.0	10,000	.089	.298	320	117.3	39.4*	.089	298
		RT	40.0	10,000	.089	.298	320	117.3	64.5*	.089	298
		RT	40	10,000	-	-	-	-	-	-	-
		RT	40	10,000	-	-	-320	117.3	26.7*	.089	298
		RT	40	60,000?	-	-	-	-	-	.105	.318
		RT	-	-			RT	-	-	-	-

* NO FAILURE

△ PULLED TO FAILURE AT ROOM TEMPERATURE, VALUE NOT CALCULATED

▲ APPARENTLY THERE WAS NO FLAW GROWTH DURING SUSTAINED OR CYCLIC MARKING

TABLE XII
SUSTAINED FLOW GROWTH DATA FOR 5A1-2.55N(E1) TITANIUM
@ -320°F

SPECIMEN SIZE	CYCLIC FLOW PREPARATION OR MARKING	INITIAL FLOW SIZE	SUSTAINED TEST	CRITICAL FLOW SIZE		K _{IC} (KSI) (N/mm ²)
				TIME @ G _{max} (HRS)	FLAW LENGTH (IN)	
9T-29 .197 2.00 RT	40.0 5,000 RT	.089 .325 .062	-320 /21.6 5.4*	-	-	59.0
	40.0 1,000		-320 /26.7 .4*			
			-320 /28.3 .7*			
			-320 /30.0 .3*			
			-320 /31.7 .8*			
			-320 /33.3 .5*			
			-320 /35.0 1.6*			
			-320 /39.6 2	-	-	68.3
			-320 /45.0 3	-	-	
9T-30 .194 2.00 RT	40.0 5,000 RT	.093 .349 .065	-320 /15.0 2	.107	.366	57.2 59.9
					.071	

* NO FAILURE

1 PULLED TO FAILURE

2 BROKE UPON LOADING

TABLE XI
SUSTAINED FLOW GROWTH DATA FOR 591-2.5 in (ECL) TITANIUM
@ -320°F

SPECIMEN SIZE	CYCLIC FLOW PREPARATION OR MARKING	INITIAL FLOW SIZE	SUSTAINED TEST	CRITICAL FLOW SIZE		K _{Ic} (k ₁₂₁ l ₁₂₁)
				TIME @ MAX STRESS (hrs)	MAX STRESS (psi)	
9T-23 .193 2.00 RT 40.0 5,000 .097 .349 .066 -320 113.0 9.9 *						56.6
				-320	118.6 4.0 *	
				-320	124.5 4.0 *	
				-320	130.7 16.0 * 1.07	68.6
				-320	134.2 [2] -	
				-320	134.2 [2] -	10.4
				-320	148.6 4.2 *	58.5
				-320	124.5 4.0 *	
				-320	129.8 [2] -	67.1
				-320	122.4 [2] -	58.2
9T-22 :194 2.00 RT 40.0 5,000 .089 .347 .064 -320 118.6 4.2 *						
				-320	124.5 4.0 *	
				-320	129.8 [2] -	
				-320	122.4 [2] -	
9T-32 .201 2.00 RT 40.0 4,000 .087 .345 .063 -320 122.4 [2] -						
				-320	122.4 [2] -	

* NO FAILURE

[1] PULLED TO FAILURE

[2] BROKE UPON LOADING

TABLE III
SUSTAINED FLOW GROWTH DATA FOR 5Al-2.5Mn(FeI) TITANIUM
@ -320°F

SPECIMEN SIZE	CYCLIC FLOW PREPARATION OR MARKING	INITIAL FLOW SIZE	TEST	CRITICAL FLOW SIZE		K _{Ic} (kSI) [in]
				FLAW DEPTH a - (in)	FLAW LENGTH 2c - (in)	
9T-72	NUMBER THICKNESS (in)	2.03	RT	40.0	4.000	K _{Ic} (kSI) ~ 0 FLAW SIZE
9T-83	NUMBER WIDTH (in)	2.01	RT	40.0	3.000	K _{Ic} (in) ~ 0.65
	NUMBER OF CYCLES					
	MAX. STRESS (kSI)					
	TEMP. oF					
	WIDTH (in)					
	THICKNESS (in)					
	SPECIMEN NUMBER					

* NO FAILURE

PULLED TO FAIRVIEW

2 → BROKE UPON LOADING

TABLE XIII
SUSTAINED FLAW GROWTH DATA FOR 51Cr-2.5% Mn (ECL) TITANIUM
@ -423°F

* NO FAILURE

> PULLED TO FAILURE

BROKE UNION COORDINATING

TABLE XIII
SUSTAINED FLOW GROWTH DATA FOR 5A6-2.5IN (62.5) TITANIUM
@ -423 °F

SPECIMEN NUMBER	THICKNESS (IN)	WIDTR (IN)	TEMP. °F	NUMBER OF CYCLES	MAX. STRESS (KSI)	TEST TEMP.	(°F)	TIME @ Lmax (hrs)	MAX. STRESS (KSI)	TEST LENGTH (IN)	FLAW DEPTH -a (IN)	FLAW LENGTH -c (IN)	FLAW SIZE -b (IN) ~ Ø	FLAW SIZE 3215	KIIc (N)	KIIc (N)	KIIc (KSI)
5T-24	.195	2.00	RT	40.0	25,000	.049	.210	.037	-423	136.8	1.8*	-	-	-	51.2	-	-
5T-79	.199	2.00	RT	40.0	20,000	.050	.186	.035	-423	137.1	8.9*	.050	.186	.035	49.9	49.9	49.9
5T-76	.208	2.00	RT	40.0	20,000	.048	.181	.034	-423	137.0	3.5	-	-	-	49.1	-	-

* NO FAILURE

▲ PULLED TO FAILURE

△ BROKE UNION LOADING

◆ ACCIDENTAL OVERLOAD

◆ SPECIMEN UNCODED AND WARMED
U TO RT OVERNIGHT.

TABLE XII
SUSTAINED FLOW GROWTH DATA FOR 5A2-2.55 IN (E21) TITANIUM
@ -42.3°F

SPECIMEN SIZE	CYCLIC FLOW PREPARATION OR MARKING	INITIAL FLOW SIZE	TEST	SUSTAINED TEST	CRITICAL FLOW SIZE	KIc (KSI) KIc (KSI)					
						TIME @ 60° (hrs)	MAX STRESS (KSI)	FLAW LENGTH (in)	FLAW DEPTH (in)	FLAW SIZE (in)	KIc (KSI)
ST-74 .207	2.01	RT	40.0	20,000.054	.203	0.38	-42.3	140.4	.9*	.	53.4
		-	-	-		3	0	3.9	2	-	0
		-	-	-	-42.3	135.5		-	-	-	51.2
ST-75 .207	2.01	RT	40.0	21,000	.049	.205	.037	-42.3	140.4	1.0*	52.5
		-	-	-	-	4	0	8.2	0.49	20.5	-
		-	-	-	-	0.49	.205	.037	-42.3	7.1*	52.5
		-	-	-	-	-	-	-	-	.049	0.37
		-	-	-	-	-	-	-	-	.070	18.8
		-	-	-	-	-	-	-	-	-	22.3
		-	-	-	-	-	-	-	-	-	22.9
		-	-	-	-	-	-	-	-	-	55.5
* NO FAILURE											
1 PULLED TO FAILURE											SPECIMEN UNCOOLED OVERNIGHT BUT EXCEPT BELOW 0°F TEMP. IN CLOSED CHAMBER
2 BROKE UPON LOADING											LOAD DROPPED TO ZERO BECAUSE OF PUMP MALFUNCTION
3 SPECIMEN WAS ALLOWED TO WARM UP TO ABOUT -150°F DURING THE TIME IT TOOK TO FIX THE PUMP UPON SATURATION OF TEST SPECIMEN BECAUSE UPON COOLING											SPCIMEN UNCOOLED OVERNIGHT BUT EXCEPT BELOW 0°F TEMP. IN CLOSED CHAMBER

TABLE XII
SUSTAINED FLAW GROWTH DATA FOR 5 Al-2.5Sn (ELI) TITANIUM
@ -423°F

SPECIMEN SIZE	CYCLIC FLAW PREPARATION OR MARKING	INITIAL FLAW SIZE	SUSTAINED TEST	CRITICAL FLAW SIZE		KIc (KSI) (N/mm²)
				FLAW DEPTH as (in)	FLAW LENGTH ac (in)	
6T-70 .207	2.00 RT	40.0 14,000 .072	.238 .046	-423 1/16.5	2	- - - 48.6
6T-69 .207	2.00 RT	40.0 15,000 .073	.235 .045	-423 1/19.2	2	- - - 49.2
6T-54 .202	2.01 RT	40.0 15,000 .074	.248 .047	-423 1/10.5	6.7*	.074 248 .047 46.8
	RT	60.0 3,000 .074	.248 .047	-	.115	.299 .060 25.4 28.7
	-	-	.115 .299	-320 1/09.7	2	- - - 52.8
9T-60 .199	2.00 RT	40.0 3,000 .089	.368 .063	-423 83.6	4.0*	.089 .368 .063 40.9
	RT	50.0 2,000 .089	.368 .064	-	.107	.395 .072 .072 24.6 26.1
	-	-	.107 .395	-320 1/00.3	2	- - - 52.4

* NO FAILURE

1 PULLED TO FAILURE

2 BROKE UPON LOADING

TABLE XXX
MECHANICAL PROPERTIES OF 2219-T87 ALUMINUM PLATE

SPECIMEN IDENTIFICATION	TEST TEMPERATURE (°F)	GRAIN ORIENTATION	GAGE DIAMETER (IN.)	GAGE WIDTH (IN.)	ULTIMATE STRENGTH (KSI)	OFFSET 0.2%	YIELD STRENGTH (KSI)	ELONGATION (%) IN GAGE LENGTH SHOWN)	ONE INCH GAGE LENGTH	TWO INCHES GAGE LENGTH	ELONGATION (%) IN GAGE LENGTH SHOWN)
A-1	427	T	.4997	.4997	70.1	57.9	51.3	10.5			
A-2	-320	T	.4997	.4986	79.4	66.1	59.6	9.5			
A-3	-423	T	.4986	.4992	101.1	71.6	60.4				
A-4	-423	T	.4992		103.9	75.5	69.4				

TABLE VIII
STATIC FRACTURE TOUGHNESS DATA OF 2219-T87 ALUMINUM PLATE

SPECIMEN SIZE (IN.)	THICKNESS ($\frac{t}{w}$)	TEST TEMPERATURE ($^{\circ}F$)	FLAW SIZE (IN.)	FLAW DEPTH (a)	FLAW LENGTH (2c)	FLAW SIZE (a/c)	FRACTURE STRESS (ksi)	$K_C \sim KSI/\sqrt{in}$	REMARKS
AA-2	.668	6.00	R.T.	.299	1.250	.223	37.6	-	34.5
CA-8	.657	6.00	R.T.	.223	.772	.154	46.6	-	35.7
DA-14	.656	6.00	R.T.	.172	.576	.120	53.5	-	36.0
AA-3	.655	6.00	-320	.295	1.238	.219	41.7	-	37.9
CA-7	.666	6.00	-320	.220	.778	.154	54.1	-	41.4
DA-13	.655	6.00	-320	.172	.574	.119	62.6	-	41.7
AA-4	.650	6.00	-423	.333	1.219	.228	44.1	-	41.1
CA-9	.657	6.00	-423	.229	.789	.156	56.5	-	43.6
DA-16	.669	6.00	-423	.174	.600	.121	63.6	-	43.2

TABLE XIX
COMBINED CYCLIC FLAW GROWTH DATA FOR 2219-T87 ALUMINUM
(@ -320°F)

SPECIMEN SIZE	CYCLIC FLAW PREPARATION	INITIAL FLAW SIZE	CYCLIC TEST		CRITICAL FLAW SIZE	$\Delta\sigma \sim 0$ (N)	FLAW SIZE	CYCLES TO FLAW	FLAW LENGTH RC (IN)	FLAW DEPTH RC (IN)	FLAW DEPTH (MM)	CYCLIC FREQUENCY (KSI)	MAX STRESS (KSI)	NUMBER OF CYCLES	NUMBER OF TESTS	TEMP OF TEST	WIDTH (IN)	THICKNESS (IN)	SPECIMEN NUMBER	NUMBER DA-56 .650 6.00 RT 15.0 5,000 .322 1,226 .220 -320 29.2 34 .490 1,859 .334 1,262 26.8 32.9*	
			TEST	TEST																	
DA-55 .658 6.00 RT 15.0 5,000 .317 1,175 .213 -320 29.2 1 .529 1,940 .354 1,047 26.4 33.9*																					
DA-6 .656 6.00 RT 11,500 .377 1,319 .245 -320 29.2 .3 .480 1,775 .323 291 28.2 32.5*																					
DA-29 .650 6.00 RT 15.0 18,000 .169 .569 .111 -320 43.8 34 .361 1,097 .220 990 48.5 40.1																					
DA-26 .657 6.00 RT 15.0 18,000 .165 .544 .107 -320 43.8 / .403 1,333 .261 1,260 28.0 43.6																					
DA-30 .663 6.00 RT 15.0 29,000 .161 .548 .106 -320 43.8 .3 .392 1,203 .240 1,694 27.8 41.9																					

* NOT COMPENSATED FOR DEEP FLAW EFFECT.

TABLE XX
COMBINED CYCLIC FLAW GROWTH DATA FOR 2219-T87 ALUMINUM
@ -320°F

SPECIMEN SIZE	CYCLIC FLAW PREPARATION	INITIAL FLAW SIZE	CYCLIC TEST	CRITICAL FLAW SIZE	
				CYCLE NO. ~ (N)	FLAW SIZE IN. ~ Ø
AA-54 .674 6.00 RT	15.0	.4,000	.310 1.176 .114	-320 35.4	.456 1.514 .290
AA-5 .663 6.00	10.0	15,000	.313 1.203 .218	1	.448 1.677 .308
AA-53 .660 6.00	15.0	5,000	.314 1.183 .217	.3	.349 1.297 .239
AA-60 .654 6.00	15.0	6,000	.308 1.164 .212	.03	.370 1.368 .252
AA-57 .663 6.00 RT	15.0	6,000	.317 1.181 .217	.3	.383 1.415 .260
DA-28 .666 6.00 RT	15.0	18,000	.174 .594 .119	-320 53.2	.237 .701 .145
DA-46 .652 6.00	15.0	16,000	.165 .576 .114	1	.365 .943 .194
DA-15 .670 6.00	15.0	15,000	.162 .597 .116	.3	.273 .779 .163
DA-27 .652 6.00 RT	15.0	16,000	.161 .561 .111	-320 53.2	.253 .752 .156
					18 32.2 35.2

* SEVERAL OVERLOADS, SPECIMEN PULLED TO FAILURE @ 42.4 KSI

TABLE 287
SUSTAINED FLAW GROWTH DATA FOR 2219-T87 ALUMINUM
② RT

SPECIMEN NUMBER	CYCLIC FLAW PREPARATION OR MARKING	INITIAL FLAW SIZE	SUSTAINED TEST SIZE	CRITICAL FLAW SIZE		TEST LENGTH	TEST LENGTH
				(N)	(N)		
AA-50-668	6.00	RT	15.0	4,000	.335	1.317	.238
AA-51	6.00	RT	15.0	5,000	.304	1.210	.217
		RT	22.6	1,000	.310	1.253	.218
		-	-	-	-	.324	.272
						RT	3.3.8
AA-1	6.00	RT	10.0	20,000	.322	1.191	.221
		RT	22.6	1,000	.347	1.360	.239
		-	-	-	-	.347	.272
						RT	35.8

▽ PULLED TO FAILURE

* NO FAILURE

SUSTAINED FLAW GROWTH DATA FOR 2219-T87 ALUMINUM
TABLE XXII
@ RT

PULLED TO FAILURE
NO EVIDENCE

TABLE XXIII
SUSTAINED FLOW GROWTH DATA FOR 2219-T87 EXAMINER
② PT

PULLED TO FAILURE

NO FAIR USE

TABLE XXXV
 SUSTAINED FLAW GROWTH DATA FOR 2219-T87 ALUMINUM
 @ E.T.

SPECIMEN SIZE	CYCLIC FLAW PREPARATION SIZE	TEST MARKING	TEST	CRITICAL FLAW SUSTAINED SIZE	
				TEST	CRITICAL FLAW SUSTAINED SIZE
CA-10 .643	6.01	RT	15.0	14,000 .217 .766	.149 RT 43.0 38.1*
		RT	27.9	2,000 .228 .778	.146 - - .246 .809 .154
		-	-	- .246 .809 .163	RT 46.0 □ - - -
DA-32 .668	6.00	RT	15.0	.560 .161	.228 .778 .153
		RT	32.1	1,000 .176	.114 - - .182 .606 .116
		-	-	- .182	.606 .124 RT 50.8 .5 - -
DA-25 .664	6.00	RT	15.0	14,000 .165	.597 .112 RT 48.1
		RT	32.1	2,000 .176	.603 .115 - - .190 .783 .138
		-	-	- .190	.783 .146 RT 47.7 □ - -

PULLED TO FAILURE

* NO FAIR USE

→ FAILED UNION LOADING

TABLE XXII
SUSTAINED FLOW GROWTH DATA FOR 2219-T87 ALUMINUM
@ RT

SPECIMEN NUMBER	CYCLIC FLOW PREPARATION OR MARKING	INITIAL FLOW SIZE	TEST SIZE	CRITICAL FLOW SIZE	TEST LENGTH		TEST TEMP	FLOW DEPTH	FLRW LENGTH	TEST LENGTH	TEST LENGTH	TEST LENGTH	TEST LENGTH
					RT	RT							
DA-33	.658 6.00	RT	15.0 20,000 .173	.603	.121	RT	49.5	16.6*	.181	.616	.124	33.6	34.1
		RT	32.1 2,000 .181	.616	.117	-	-	-	-	.629	.125	21.4	22.2
		-	-	.195	.649	.123	RT	49.5	.2*	-	-	33.9	-
				-	-	-	RT	50.8	.9	-	-	-	35.0**

* NO FAILURE
** CALCULATED USING $(\bar{Q}Q) = .123 \sqrt{= 50.8 \text{ ksi}}$
FLOW GROWTH NOT MEASURED DURING
FINAL RUN WHEN STRESS WAS RAISED TO 49.5 ksi THEN TO 50.8 ksi

TABLE XXIV
SUSTAINED FLAW GROWTH DATA FOR 2219-T87 ALUMINUM
@ R.T.

APPLIED STRESS SIZEx OR MARKING	CAPAC. FLAW PREPARED TEST	INITIAL FLAW SIZE	SUSTAINED TEST	CRITICAL FLAW SIZE*
CA-34 .658 6.00	RT	15.0	13,000.212	.767 .142 RT 27.9 .4 *
- - -	-	-	-	RT 32.5 1.1 *
- - -	-	-	-	RT 37.2 1.3 *
- - -	-	-	-	RT 41.8 18.7 * .220 .800 .153 - 32.0
RT 27.9 4,000	RT	.220	.800 .147 -	-
- - -	-	-	-	RT 41.8 .164 20.9 22.0
- - -	-	.253	.875 .168 RT 37.7 .5 *	30.1
- - -	-	-	-	RT 39.8 .9 *
- - -	-	-	-	RT 40.8 .25 *
- - -	-	-	-	RT 41.8 .4 *
- - -	-	-	-	RT 43.1 .2 *
- - -	-	-	-	RT 43.7 - - - 34.9 **

△ PULLED TO FAILURE

* NO FAILURE

** CALCULATED USING $(\frac{Q}{Q_0})^{\frac{1}{2}} = .41$ ($\sigma = 43.7 \text{ ksi}$, FLAW EXTENDED DURING SUSTAINED TEST, FLAW NOT NECKED).

TABLE XXII
SUSTAINED FLOW GROWTH DATA FOR 2219-T87 ALUMINUM
@ -320°F

SPECIMEN NUMBER	CYCLIC FLOW PREPARATION OR MARKING	INITIAL FLOW SIZE	SUSTAINED FLOW SIZE	CYCLIC FLOW SIZE	TEST
AA-58	660 6.00 RT	15.0 5,000	RT	1.192 .222	-320 39.6 .03 - - - 36.4
AA-49	.666 6.00 RT	15.0 5,000	.305 1.192	.216 -320 37.5 19.7*	.339 1.356 .240 34.0 35.8
-320	25.0 1,000	.330 1.356	.234 -	- - .330 1.356 .234	23.6 23.6
-	-	.330 1.356	.242 -320 39.6 .12 -	- - - 38.0	
AA-52	.663 6.00 RT	15.0 5,000	.313 1.192	.218 -320 38.5 10 sec	- - - 35.1
AA-59	.657 6.00 RT	15.0 5,000	.310 1.182	.216 -320 37.5 .3*	34.0
				-320 38.6 16.0*	
				-320 39.6 .4*	
				-320 40.6 .01 - - -	
				- - - 37.0 *	

* NO FAILURE

** CALCULATED USING $(\frac{g}{\sigma}) = .218$, $\sqrt{\sigma} = 40.6$

FLOW GROWTH NOT MEASURED.

TABLE XXXIII
SUSTAINED FLAW GROWTH DATA FOR 2219-T87 ALUMINUM
② - 320°F

SPECIMEN SIZE	CYCLIC FLAW PREFATIGUE OR MARKING	INITIAL FLAW SIZE	TEST TEMPER	CRITICAL FLAW SIZE	
				12	18
CA-11 .658 6.00 RT	15.0 10,000 .229 .804	.157	-320 48.6	17.1	.240 .874
CA-38 1.664 6.00 RT	15.0 11,000 .207 .785	.149	-320 48.7	18.8 *4.2	.800 .152
-320	32.5 1,000 .212 .800	.145	-	-	.228 .814
-	-	.228	.814	.21.8 *2.37	.840 .165
-320	32.5 1,000 .237 .840	.156	-	-	.241 .849 .158
-	-	.241	.849	.20	-
CA-40 1.673 6.00 RT	15.0 13,000 .212 .795	.149	-320 43.3	120.0 *2.24	.812 .154
-320	32.5 1,000 .224 .812	.150	-	-	.238 .864 .159
-	-	.238	.864	.167	-
					* NO FAILURE

TABLE XXX

SUSTAINED FLAW GROWTH DATA FOR 2219-T87 ALUMINUM
@ -320°F

SPECIMEN SIZE	CYCLIC FLAW PREPARATION SIZE	SUSTAINED FLAW TEST OR MARKING	CRITICAL FLAW SIZE	TEST TEMPERATURE	
				152°F	238°F
CA-48 .659 6.00 RT	15.0 10,000 .213	.750	.142	-320	37.9
	-320	32.5 1,000 .216	.750	-.139	-.216
	-	-	-.241	.795	.247
CA-47 .649 6.00 RT	15.0 10,000 .216	.848	.151	-320	50.1
	-320	32.5 1,000 .242	.830	.156	-.246
	-	-	.246	.851	.25.3
				.170	55.4
				-	-
					44.6
					-
					38.5

* NO FAILURE

D PULLED TO FAILURE

TABLE XXX

SUSTAINED FLAW GROWTH DATA FOR 2219-T87 ALUMINUM
 @ - 320°F

SPECIMEN NUMBER	CYCLIC FLOW PREPARATION	INITIAL DRAW SIZE	SUGGESTED CRITICAL DRAW SIZE	OR MARKINGS	TESTS							
					DA-16	DA-17	DA-18	DA-19	DA-20	DA-21	DA-22	DA-23
DA-31	6.00	RT	15.0	16,000 .168 .599 .119	-320	56.4	48.0*	.184	.603	.123	38.1	38.7
			RT	16,000 .184	.603	.113	-	-	.184	.603	.113	9.9
				- - -	.184	.603	RT	51.6	1	-	-	36.5
												40.0
												-
DA-35	.658	6.00	RT	15.0 20,000 .165	.545	.112	-320	59.5	.05	-	-	38.9
												-
DA-31	.665	6.00	RT	15.0 18,000 .156	.574	.113	-320	56.4	18.9	.179	.572	.118
									-	-	.179	.572
											.111	24.5
												44.5
												40.0
DA-36	.655	6.00	RT	15.0 20,000 .175	.596	.120	-320	56.3	.3	-	-	38.8

X NO FAIR USE

► PULLED TO FAILURE

TABLE XXXT
SUSTAINED FLAW GROWTH DATA FOR 2219-T87 ALUMINUM
@ -423°F

SPECIMEN SIZE	CYCLIC FLAW PREPARATION	INITIAL FLAW SIZE	SUSTAINED TEST	CRITICAL FLAW SIZE	MARKING		FLAW LENGTH	FLAW DEPTH										
					TEM	RT												
DA-18 .670 6.00	RT	.15.0 18.000	.189	.598	.121	-423	57.2	44.0*	.199	.601	.123	38.8	39.2					
	RT	.15.0 18.000	.199	.601	.115	-	-	-	.199	.601	.115	9.9	9.9					
	-	-	-	.199	.601	.126	RT	50.5	▽	-	-	-	-	35.1				
CA-45 .658 6.00	RT	.11.000	.211	.761	.146	-423	50.9	9.9*	.219	.767	.148	37.9	38.2					
	RT	.27.9 3.000	.219	.767	.143	-	-	-	.261	.945	.174	20.6	22.7					
	-	-	-	.261	.945	RT	46.9	▽	-	-	-	-	-	39.3*				
AA-61 .661 6.00	RT	10.0 3.000	.274	.123	.198	-423	44.6	10.3*	.286	.123	.202	34.4	34.8					
	RT	.15.0 6.000	.286	.123	.195	-	-	-	.311	.123	.211	12.9	13.5					
	-	-	-	.311	.123	.221	RT	48.5	▽	-	-	-	-	31.6				

* NO FAILURE

▽ PULLED TO FAILURE

** SPECIMEN WAS DELAMINATED

TABLE XXXII
SUSTAINED FLAME GROWTH DATA FOR 2219-T87 ALUMINUM
@ -423°F